Power-law behavior at the order-disorder transition of colloidal suspensions under shear flow

Dept. of Pure and Applied Science, Univ. of Tokyo M. J. Miyama[1], S. Sasa

せん断流下のコロイド分散系において、平衡条件下と同様に秩序-無秩序相転移が起きることが知られている。しかし、せん断流下の秩序相においては粒子配置は刻一刻と変化しており、本質的に平衡系のコロイド結晶とは異なる状態である。このような非平衡条件下における相転移を明確に特徴付けるためには系の動的な振る舞いに着目することが重要であり、本研究では系が定常状態に達した後の構造因子の時間変化を数値計算により測定した。この結果、秩序相では構造因子のフーリエ変換のパワースペクトルがべき的な振る舞いを見せ、特に低周波数領域では $1/f$ 的になることが見出された。

1 Introduction

1.1 Colloidal crystal in equilibrium systems

Under equilibrium condition, the crystalline configuration of colloidal particles, so-called "colloidal crystal" is observed in the low temperature case. As increasing the temperature of the system, the orderly periodic arrangement disappears and particles act like a fluid. This is the order-disorder transition and it is characterized as the discontinuous jump of the first maximum of the structure factor S_{m} defined as

$$S_{\mathrm{m}} \equiv \max_{k} \left| \frac{1}{N} \tilde{\rho}(k) \tilde{\rho}^{*}(k) \right|, \tag{1}$$

where N is a number of particles in the system, and $\tilde{\rho}(k)$ is the Fourier transform of the density field for a given configuration.

1.2 The order-disorder transition in sheared systems

Similarly, in colloidal suspensions under shear flow, we can observe the discontinuous jump of S_{m} regardless of the existence of flow [1]. There are obviously two different phases that correspond to crystal and fluid in equilibrium systems. However, in this situation, the particles drift along shear flow so that it is far from the static concept of "crystal" and the criterion of the melting in equilibrium systems seem to be not available in the non-equilibrium system. So, we conjecture that it is not enough to consider the static feature of this system for understanding the order-disorder transition in sheared system.

[1]E-mail: miyama@jiro.c.u-tokyo.ac.jp

2 Results by using Brownian dynamics simulations

2.1 Order parameter $\hat{S}_{\rm m}(t)$

We identify the ordered and disordered phases in the sheared system by noting the difference of the behavior of the power spectrum,

$$\hat{S}_{\rm m}(\omega) = \int_{-\infty}^{\infty} {\rm d}t\, s_{\rm m}(t) \exp(-i\omega t), \tag{2}$$

where $s_{\rm m}(\omega)$ represents time dependent value of the maximum of structure factor with time t.

2.2 Power-law behavior in the ordered phase

We performed Brownian dynamics simulations with Lees-Edwards periodic boundary conditions. Our main result with shear rate $\dot{\gamma} = 0.001$ are shown in fig. 1. In the lower temperature regime than $T = 0.16$ (ordered phase), the power-law fluctuations are observed and its exponent is -2 in the higher frequency regime than the shear rate $\dot{\gamma}$ and -1 in the lower frequency regime, while it exhibits the white noise type fluctuation in the high temperature case $T = 0.18$ (disordered phase). We conclude that it is the clear characterization of the order-disorder transition of colloidal suspensions under shear flow.

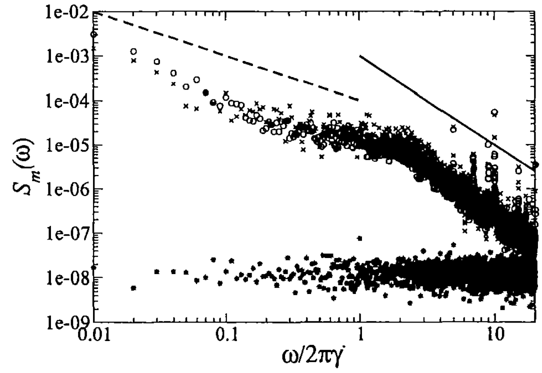

Figure 1: Spectra $\hat{S}_m(\omega)$ as a function of $\omega/2\pi\dot{\gamma}$ where $\dot{\gamma}$ is fixed parameter $\dot{\gamma} = 0.001$. $T = 0.14$ (X), 0.16 (circle) and 0.18 (star). The solid line represents ω^{-2} slope and the dashed line ω^{-1} slope.

References

[1] M. J. Miyama and S. Sasa, cond-mat/0706.4386.

[2] P. Holmqvist, M.P. Lettinga, J. Buitenhuis and J.K.G. Dhont, Langmuir, **21** (2005), 10976.